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B71 04048

date: April 23, 1971

to: Distribution

from: M. T. Yates

subject: A Philosophy for S-IVB Impact Point Targeting and Specification -- Case 340

ABSTRACT

Three criteria that should be considered in the real-time targeting of the S-IVB stage are:

1. Adequate range from the impact to all operating seismometers (at least 250 km for Apollo 15)

2. Minimum uncertainty in the post-flight determination of the range

3. The specified azimuths from the impact to the seismometers.

The specification of the S-IVB impact point should consider the effect of potential miss distances of up to 350 km as well as the tendency for errors in the post-flight impact point determination to reside mostly in the north-south direction.

(NASA-CR-118420) A PHILOSOPHY FOR S-4B IMPACT POINT TARGETING AND SPECIFICATION (Bellcomm, Inc.) 7 p

N79-73423

Unclas
00/91 12852

FF No. 602

(PAGES)

CR-118420

(NASA CR OR TMX OR AD NUMBER)

01

(CODE)

30

(CATEGORY)

[redacted]

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MEMORANDUM FOR FILE

The ultimate goal of the S-IVB lunar impact maneuver is to achieve an impact of the spent stage at a pre-selected point on the moon's surface. This is accomplished by alternately tracking the stage and thrusting until a satisfactory trajectory is achieved. Due to the exigencies of limited stage life, APS fuel, and tracking time this process results in an impact point that may be as much as 350 km from the desired point. In addition, the actual impact point is determined by projecting the observed trajectory until it intersects the moon's surface. Uncertainties in the tracking data and in the location of the moon can result in uncertainties in the calculated range from the impact to the seismometer of 15 km or more. Thus it is useful to detail a philosophy of impact point targeting and specification that, within the constraints of scientific desirability and operational necessity, maximizes the probability of achieving a satisfactory impact point and minimizes the uncertainty in the final range determination.

Targeting

The primary usefulness of the S-IVB impacts is to provide a large amount of seismic energy injected into the moon at a known distance and time so that the physical structure of the moon as a function of depth can be inferred from the resultant signals detected by the seismometers. The key word here is depth. The S-IVB seismic experiment is a profiling experiment; i.e., its purpose is to determine the variation of physical parameters (density, seismic velocity) with depth. Seismic energy penetrates into the moon from the impact point and then, because of the increase of seismic velocity with depth, is refracted back up toward the surface much as light is refracted by a lens. The maximum depth that the energy can reach and still be refracted sufficiently to reach the seismometer is approximately proportional to the distance from the impact point to the seismometer. Thus the Apollo 13 impact at 135 km range produced detectable energy that penetrated about 20 km into the moon. The Apollo 14 impact was to hit 300 km away and provide information down to 40 km. In order to build up a profile of the moon, then, ever increasing ranges to the impact points are needed so that deeper regions of the moon are sampled. Therefore, the first priority goal of the targeting maneuver is to achieve an adequate range to all operating seismometer stations. Adequate in this sense would mean at least 50% greater than the longest range so far achieved. For the Apollo 15 impact this would be 250 km. Thus a course correction would be desirable if the projected impact is less than 250 km from either the ALSEP 12 or 14 seismometer.

It is not correct, however, merely to say the farther the better, because the detected signal strength decreases with increasing range. How far away one can detect an S-IVB impact is conjectural at present; indeed it has been suggested by Latham that spent stage impacts could be detected at the maximum range of 1/2 the lunar circumference. To be conservative, however, one might set a maximum acceptable range at 20% greater than the maximum nominal range. For Apollo 15 the maximum nominal range is 480 km (to the Apollo 12 ALSEP) so that 575 km would be a conservative upper limit for range.

These range criteria as well as the azimuth criteria to be mentioned later are shown on Figure 1. The 350 km impact footprint is also indicated on this figure. About 2/3 of this footprint lies in preferred or acceptable regions.

A second priority objective of the impact maneuver would be to achieve an impact point that allowed a minimum uncertainty in the post flight analysis of range of impact from instruments. Almost all of the analyses of the seismic data depend on an accurate number for the range, and uncertainties in this basic parameter are directly reflected in the final results. Therefore, any maneuvers that are likely to degrade the final range precision should be avoided and operational techniques to improve this precision should be sought. It should be noted that the requirement is accurate range to the seismometers, which is not necessarily equivalent to accurate latitude and longitude of the impact point. The optimum accuracy for the range determination is ±1%, or a few kilometers at the ranges of interest.

A third priority goal in the real-time targeting maneuver would be to achieve (within, say, ±10°) the specified azimuth from the impact point to the seismometers. In a radially symmetric moon, azimuth would not be a relevant factor. However, there are indications that significant lateral inhomogeneities may exist both near the surface and at depth within the moon. Certainly, the boundary between highland and mare regions is likely to represent a seismic discontinuity of detectable magnitude. Thus the azimuth to the seismometers is an important specification of the impact point, although second in priority to range considerations.

Specification

The major factor in choosing the S-IVB impact point and the one that is beyond the scope of this paper is simply the scientifically desirable ranges and azimuths from that point to the seismometers. This in turn depends on the history of past impacts, the present locations of seismometers, the number of future impacts that are likely to be available, and one's notion of what the moon is like. The initial impact (Apollo 13) was targeted 200 km from the ALSEP 12 seismometer, and 135 km was actually achieved. The second impact (Apollo 14) was targeted 300 km from the seismometer with 172 km achieved. The Apollo 15 impact is to be the first S-IVB to be detected by two seismometers and will be targeted to hit 300 km from ALSEP 14 and 480 km from ALSEP 12.

However, in addition to the scientific considerations that led to the choice of these points there exist engineering and operational factors that should also be considered. The most obvious is, of course, the 350 km radius pre-maneuver footprint for the impact. Although this is a worst-case number assuming virtually no tweaking of the trajectory after an initial projected impact point is determined, it should not be dismissed as impossible; the Apollo 14 impact missed its specified target point by 280 km. A second order aspect of this uncertainty is that the footprint is not a circle but an ellipse whose eccentricity and orientation is a function of both the landing site for the mission and the impact point for the stage. However, except for high latitude impacts or impacts far to the east, the ellipticity of the dispersion footprint is relatively small.

In addition to a large uncertainty in the predicted impact point, the nature of the post-flight error analysis should also be considered in choosing an impact point. For example, the detailed analysis of the Apollo 13 impact, Ref. 1, revealed that the coordinate of the impact point was 27.9 ± 0.1°W longitude by 2.5 ± 0.5°S latitude, i.e., ±15 km uncertainty in the north-south direction and only ±3km uncertainty in the east-west. The tighter error bars in longitude are a direct result of having an accurate impact time to constrain the solution. In this case the impact was almost due west of the seismometer so that the uncertainty in range (-3.8, +5.4 km) was controlled more by the longitudinal precision than the latitudinal. Since the optimum range accuracy is on the order of 1%, ±3 km (=0.1° of latitude) error is a significant improvement over a ±15 km (=0.5° of longitude) error at ranges of 300 to 500 km. Hence the S-IVB should be targeted generally east-west of the seismometer if maximum range precision is desired.

<u>Summary</u>

Decision points in the real-time targeting of the S-IVB stage should consider the following criteria in order of priority:

1. adequate range from the impact to all operating seismometers,

2. minimum uncertainty in the post-flight determination of the range,

3. the specified azimuths from the impact to the seismometers.

The specification of the S-IVB impact point should consider the effect of relatively large potential miss distances between the desired and the actual impact points as well as the tendency for errors in the post-flight impact point determination to reside mostly in the north-south direction.

Michael Yates

2015-MTY-dmu M. T. Yates

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Reference 1: AS-508 S-IVB Post-flight Lunar Impact Trajectory Analysis, NASA Technical Memorandum TM X-64563, November 9, 1970.

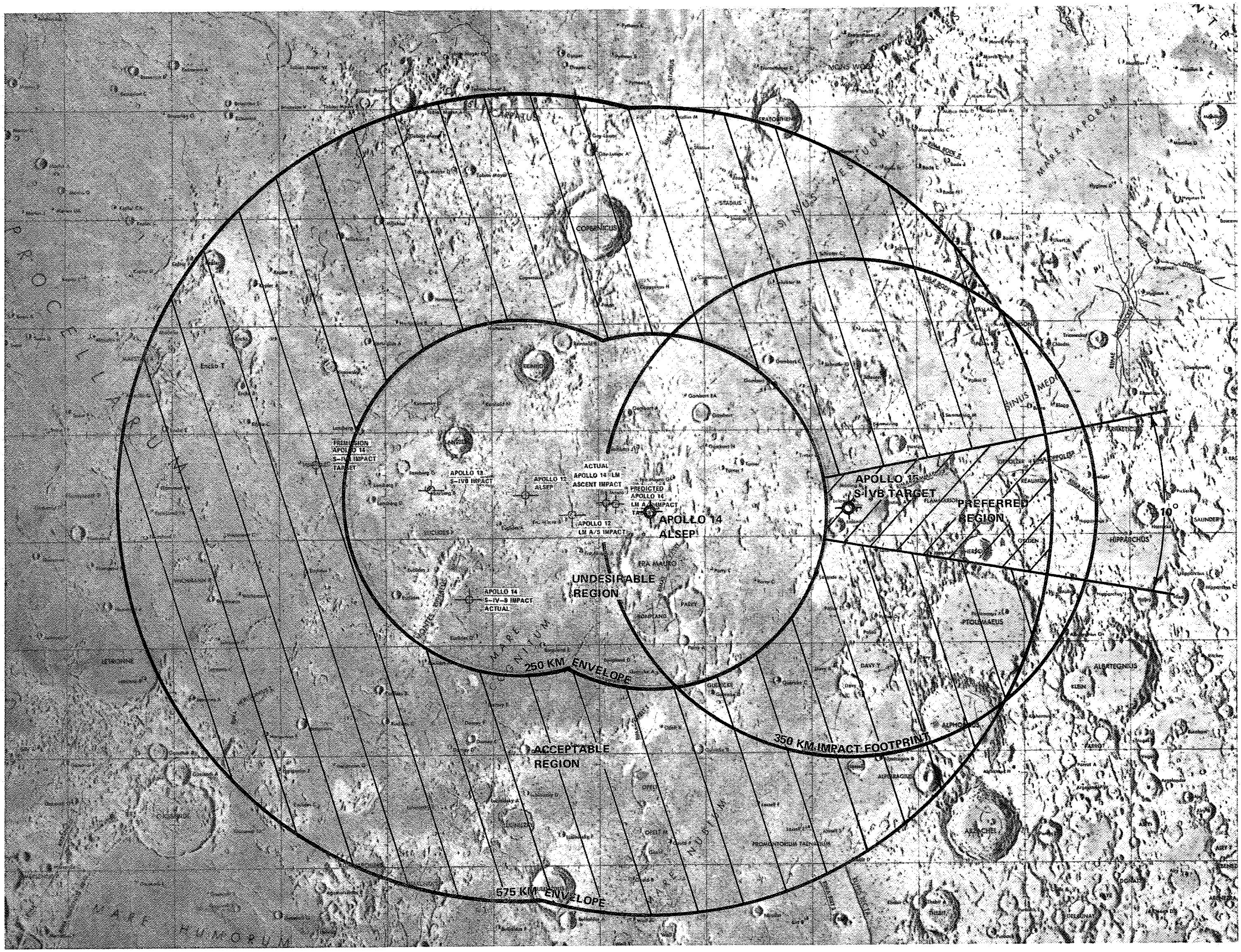

FIGURE 1 - TARGETING REGIONS FOR THE S-IVB